

The University of Chicago

HIGH ALTITUDE TEST OF RADIO-EQUIPPED
COSMIC RAY METER

A DISSERTATION SUBMITTED TO THE
FACULTY OF THE DIVISION OF THE
PHYSICAL SCIENCES IN CANDIDACY FOR
THE DEGREE OF DOCTOR OF PHILOSOPHY

DEPARTMENT OF PHYSICS

1937

By

CORNELIUS DOUWE KEEN

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HIGH ALTITUDE TEST OF RADIO-EQUIPPED COSMIC RAY METER.

BY

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ABSTRACT.

A high altitude cosmic-ray meter, of the type proposed by Benade,⁴ has been built and flown. The ionization current in an unshielded argon-filled chamber moves the mirror of a Dershem electrometer. When the reflected light beam falls on a photoelectric cell, the electrometer is discharged and the radio signal is modulated. A pressure device also modulates the signal when certain altitudes are reached. A small quantity of radioactive material introducing a small fixed ionization makes possible convenient measurement of cosmic-ray ionization varying through a large ratio. On April 14, 1936, a balloon flight was made from Shreveport, Louisiana. The instrument and batteries weighed 41 pounds, and were raised by three 8-foot balloons to an altitude of 52,000 feet. During the rapid ascent the swaying of the gondola affected the electrometer mirror, and the cosmic-ray signals were irregular. More satisfactory data were obtained on the slower descent. At 78 mm. of mercury an intensity of 288 standard ions was measured. This preliminary curve is somewhat steeper than that obtained by Millikan and Bowen⁷ at about the same latitude. The test has shown that in principle the method is feasible, but that changes in the construction of the electrometer are necessary before wholly satisfactory results can be obtained.

INTRODUCTION.

In order to gain a more complete understanding of cosmic radiation, it is necessary to learn how this radiation varies from place to place on the earth's surface and from sea level to the greatest altitudes which can be reached. Much work has been done in this direction, particularly during the last decade. To study the altitude effect, airplane flights carrying self-registering apparatus have been made at several localities,¹ the maximum height reported being 29,000 feet. Much

¹ R. A. Millikan and R. M. Otis, *Phys. Rev.*, **27**, 645, 1926. K. Buettnner, *Zs. f. Geophys.*, **3**, 170 and 236, 1927. J. Clay, *Kon. Ak. Wet.*, Amsterdam, **36**, 1265, 1927. Bowen, Millikan and Neher, *Phys. Rev.*, **44**, 246, 1933. Mott, Smith and Howell, *Phys. Rev.*, **44**, 4, 1933. G. A. Suckstorff, *Zs. f. Geophys.*, **10**, 95, 1934. Clay and Van Alphen, *Physica*, **2**, 183, 1935. S. N. Vernoff, *Phys. Rev.*, **46**, 822, 1934. Millikan, Neher and Korff, *Phys. Rev.*, **49**, 871, 1936.

greater altitudes (60–72,000 feet) have recently been reached by manned balloon flights² but these have necessarily been made at mid-latitudes on the Northern hemisphere. Their cost and the personal hazards involved make them unsuited for an extensive research program. Unmanned balloons, equipped with self-registering cosmic ray apparatus, have been flown to 90,000 feet.³ In this method of stratosphere exploration the success of the experiment depends on the finding and return of the instruments to the experimenter. The apparatus required is not heavy and small balloons are sufficient to carry the equipment to great heights.

A fourth procedure is to have the measuring apparatus transmit its readings by radio to the observer on the ground, while the flight is in progress. Using this technique, the finding and return of the apparatus are not requisite and the method is thus available at any location. On the other hand the instrumentation is more complicated than for self-registering apparatus and the greater weight sets additional problems. This procedure was initiated by Prof. J. M. Benade,⁴ while visiting at the University of Chicago.

In the balloon experiment here described this radio technique has been used. The object was to obtain a working test of a method of measuring total intensity in the stratosphere. The test has shown that in principle the method is feasible. There are, however, important details which require development before wholly satisfactory results can thus be obtained. Since many others are now engaged upon similar experiments, it may be of interest to describe in some detail the results of this trial.

² A. Gockel, *Phys. Zs.*, **11**, 280, 1910. A. Gockel, *Phys. Zs.*, **12**, 595, 1911. V. F. Hess, *Wien. Ber. (II A)*, **121**, 2001, 1912. Kolhoerster, *Prob. Kosm. Phys.*, Hamburg, 1924. A. Gockel, *Phys. Zs.*, **16**, 345, 1915. A. Piccard and M. Cosyns, *Comptes Rendus*, **195**, 604, 1932. A. H. Compton and R. J. Stephenson, *Phys. Rev.*, **45**, 441, 1934. W. F. G. Swann and G. L. Locher, *Phys. Rev.*, **47**, 326, 1935. A. W. Stevens, *Natl. Geogr. Mag.*, **69**, 693, 1936.

³ J. S. Bowen and R. A. Millikan, *Phys. Rev.*, **43**, 695, 1933. Regener, *Naturwiss.*, **20**, 695, 1932. J. Clay, *Physica*, **1**, 363, 1934. Regener and Auer, *Phys. Zs.*, **35**, 784, 1934. Regener and Plotzer, *Phys. Zs.*, **35**, 779, 1934. Regener and Plotzer, *Nature*, **136**, 718, 1935.

⁴ J. M. Benade and R. L. Doan, *Phys. Rev.*, **47**, 198, 1935.

APPARATUS AND EQUIPMENT.

The complete system required for this experiment consists of the cosmic ray meter and gondola, auxiliary meter, balloons and the receiving apparatus. These will be described in the order named.

The Cosmic Ray Meter and Gondola.

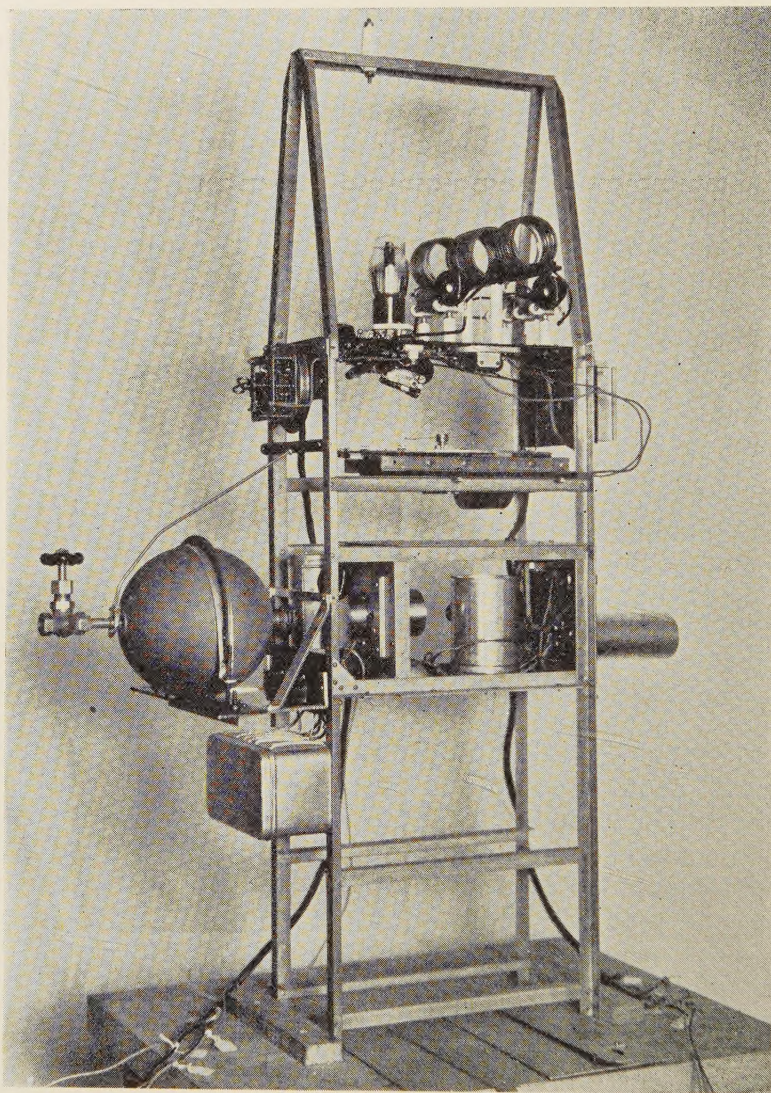
The principle of the cosmic ray meter may be briefly stated as follows: the ionization current in an unshielded argon-filled chamber moves the mirror of an electrometer. When the reflected light beam falls on a photocell, the electrometer is discharged and the radio signal is modulated. A barometric device also modulates the signal.

Figures 1 and 2 show a photograph and a detailed drawing of the instrument, while Fig. 3 gives its circuit diagram with values of resistors, condensers, etc. The $6'' \times 12'' \times 36''$ frame is made of Dow metal. Above is the 70 meter transmitter *A*. *B* is the pressure device. Under the pressure device is placed the ionization chamber *C*, connected through the shielding can *D* to a Cenco-Dershem electrometer *E*. The beam from the light source *F* is reflected by the mirror of the electrometer, when this is in the proper position, through a narrow slot in the shielding can *G*, on to a photoelectric cell. When the central electrode *N* is grounded, the lightspot will be a certain distance from the slot. As the ionization current charges the electrometer the light spot moves towards the slot. When it falls through the slot on the photocell, the current set up is amplified in the usual manner by the vacuum tube contained in *H*. The change in its plate current energizes a magnetic key in *D*, grounding the central electrode, which moves the lightspot back to its original position. At the same time the transmitter signal is modulated.

The time which elapses between two groundings of the central electrode is inversely proportional to the ionization current and therefore a measure of it. When the instrument is aloft, the radio signals therefore give information as to the intensity of the ionization current in the chamber. Shield can *K* contains the voltage supply for the electrometer. $L_1, 2$ are the platforms for the power supply.

The ionization chamber is a steel sphere of 6'' diameter,

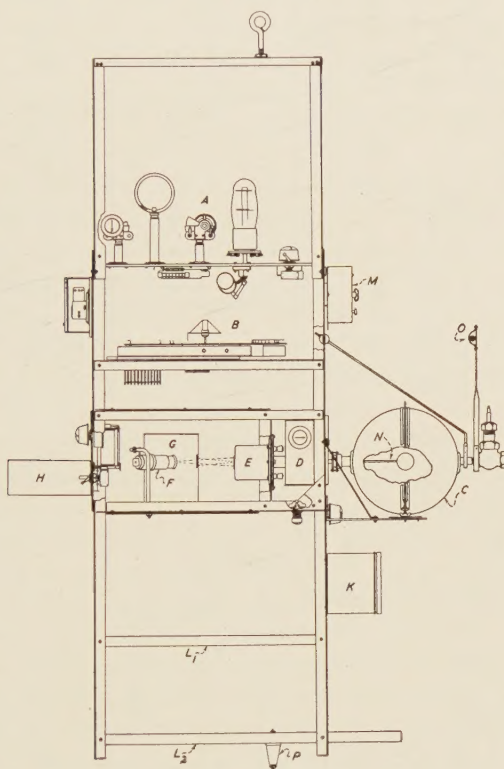
FIG. I.



The instrument.

wall thickness 0.020", filled with very pure argon at eight to ten atmospheres pressure. The supporting frame is so arranged that the chamber can be mounted or dismounted in a few minutes, which is of importance in the procedure followed. A battery of dry cells maintains the shell at + 135

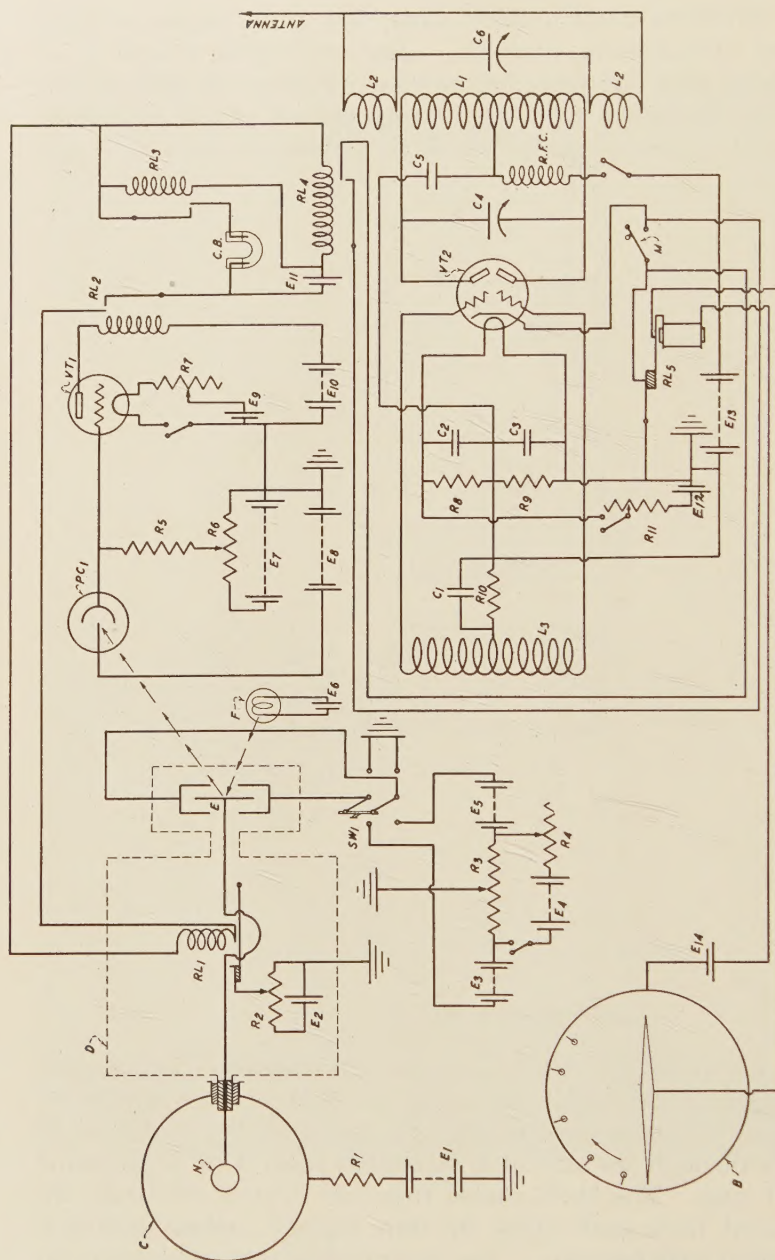
FIG. 2.



Detailed drawing of the instrument.

volts potential, through a 250,000 ohm resistor. The central electrode *N* carries at its end a 1" hollow brass sphere to produce a more uniform field in the chamber. Where *N* passes through the shell it is separated from it by a grounded guard ring. The shell, guard ring and central electrode are insulated from each other by thin tapered amber bushings, cemented with beeswax. The central electrode passes through

FIG. 3



Circuit diagram of the instrument. R_1 , 250,000 ohm; R_2 , 3 megohm; R_3R_4 , 50,000 ohm; R_5 , 50 megohm; R_6 , 1 megohm; R_7R_8 , 30 ohm; R_9R_{10} , 200 ohm; R_{11} , 5000 ohm; E_1E_{10} , 135 V.; E_2 , 1.5 V.; E_3E_6 , 36 V.; E_4 , 24 V.; $E_5E_9E_{10}$, 3 V.; E_7 , 22.5 V.; E_8 , 90 V.; E_9 , 6 V.; E_{11} , 292.5 V.; R_{12} , Headphone coil; R_{13} , Western Electric B 1003; R_{14} , Western Electric B 46; R_{15} , Buzzer coil; R_{16} , Buzzer; C_1 , 100 μ F; C_2C_3 , 0.01 μ F; C_4 , 0.002 μ F; C_5 , 0.002 μ F; RFC , Radio frequency choke; V_1 , No. 19 vacuum tube; V_2 , No. 6A6 vacuum tube; PC_1 , Visatron 72-A; L_1 , 14 turns $1/8''$ c.t., space between turns $1/10''$; Diameter $2''$; L_2 , 7 turns $1/8''$ c.t., space between turns $1/10''$; Diameter $2''$; L_3 , 54 turns No. 22 d.c.c. on $1\frac{3}{8}''$ O.D. bakelite tubing; C.B., Delayed circuit breaker; M = Clock work key.

the shield D and is connected to the needle terminal of the electrometer. The grounding key is a fine platinum wire spiral, which moves only $1/16''$. The small motion and the lengthened contact time make for a more reliable discharge.

By means of a small 1.5 volt battery and potentiometer the grounding key imparts a negative potential to the central electrode equal to half of the voltage change on the electrometer needle. The leakage current over the insulation is thus about half the time from guard ring to central electrode and flows in opposite direction during the remainder of a cycle, practically eliminating errors which might arise through changing leakage conditions.

The electrometer (E of Figs. 1, 2 and 3), developed by Dr. E. Dershem of the University of Chicago, is similar to the Lindemann instrument, but has a movable mirror which gives it a somewhat greater period.

The metal capsule O , clamped to the ionization chamber, contains a small amount of radioactive material, which adds a constant background to the radiations to be measured. By so adjusting its quantity and distance from the chamber that the background is one-fourth of the maximum intensity expected, the experimental data, instead of being nearly absent on the lower part of the curve and crowded at the top, will be more uniformly distributed. In addition, the electrometer can be used at lower sensitivity.

The shield G can be turned in its base, providing for an easy adjustment of the position of the slot. The photoelectric cell is mounted in a socket, which is filled with paraffin to prevent leakage between the terminals over the glass of the cell. The 50 megohm resistor is mounted in sealing wax in the base of the shield G and is paraffin coated.

The change in the plate current of the tube caused by the photoelectric current changing the gridbias energizes relay RL_2 (Fig. 3). The closing of its controlled circuit energizes relays RL_1 , RL_3 and RL_4 . RL_1 discharges the electrometer, the lightspot moves away from the slot in shield G , the photoelectric current ceases and RL_2 opens its controlled circuit. Relay RL_4 , when closed, short circuits the transmitter key, but since a single click would be the only signal, giving evidence of the fact that the electrometer has been discharged, another

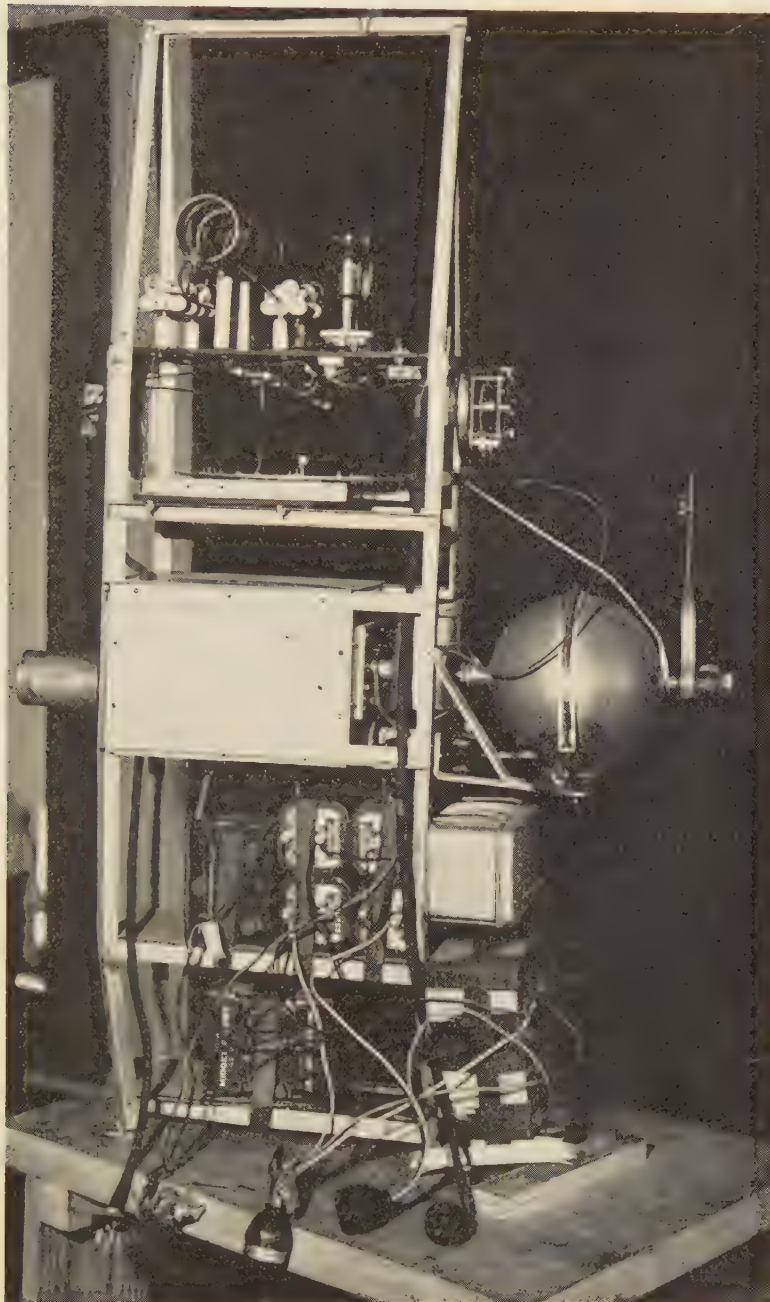
arrangement is necessary. When relay Rl_3 closes, current from E_{11} flows through the delayed circuit breaker C.B., an ingenious device, developed by Prof. J. M. Benade. It is a small U-shaped glass vessel; the electrode on one side is a spiral of fine tungsten wire, which dips in the mercury which half fills the vessel, the other terminal is a heavier tungsten wire, which likewise dips in the mercury in the other leg. The current, heating the tungsten spiral, expands the air above the mercury, which forces the mercury down until the contact is broken and the circuit opened. As soon as the plate current of the No. 19 tube drops to zero, Rl_2 opens, but the current from E_{11} passes now through the circuit breaker and holds relays Rl_3 and Rl_4 closed, until the circuit breaker opens the circuit.

The expansion of the evacuated sylphon of the pressure device B (Figs. 1, 2 and 3) is communicated by gears to the needle, which is insulated from the circular plate beneath it. The needle carries at its end a bent free swinging platinum wire, which touches the platinum contacts on the circumference of the disc, as the pressure changes. When a contact is made, circuit E_{14} is closed, which energizes buzzer Rl_5 , which is a part of the keying device and modulates the transmitter signal.

The transmitter is essentially a T.N.T. circuit.⁵ The key M placed in the cathode lead of the transmitter tube is a clockwork, the keying being done by a light platinum wire, moving back and forth with the balance wheel. The signal, unmodified by the pressure or cosmic ray device, is a series of dashes numbering 120 per minute and of $\frac{1}{4}$ second duration. When Rl_4 is held closed, the key M is short circuited and the signal becomes continuous for four seconds. When Rl_5 is energized by the pressure device, the interrupted or the continuous signal is modulated with a frequency of 50 cycles per second, giving a coarse note which can easily be recognized, both in the written and audible reception. The transmitter used in the flight had about 2 watts in the antenna and gave a signal of strength 4.5 in a ground test at a distance of 71 miles. The insulator P (Fig. 2) serves to bring the antenna wire through the gondola cover.

⁵ The Radio Amateur Handbook, 1936, 126.

FIG. 4.



Instrument after the flight.

The power supply for the instrument (except the electrometer) consists of 4 Burgess "Little Six" cells, 1.5 volts each, 7 General Dry Batteries "V-30-AA," 45 volts each, and 3 General Dry Batteries "V-30-PW," 45 volts each, weighing altogether 17 pounds. Figure 4 shows how the batteries are placed on the platforms L_1 and L_2 , L_2 being extended beyond the frame of the instrument, so that it can be balanced, when suspended from the hook at the top.

The V-30-PW's furnish voltage for the ionization chamber. At the proper taps on the V-30-AA's voltages are taken off for the photoelectric cell, "C" bias of the 19 tube and for the plates of the 19 and 6A6 tubes. The four 1.5 volt batteries in series furnish the filament current for the transmitter tube, while two of them in series supply the current for the light source. The other two in series supply the filament current for the 19 tube, the circuit breaker CB and buzzer RL_5 .

The steady current drain on the 1.5 volt batteries amounts to 1.75 amp., with a maximum drain of 2.85 amp. Two test runs were made, with fresh batteries, under flight conditions, and it was found that there is power available for a 2.5 hour flight. When the current through the circuit breaker falls too low, it does not function and the relay RL_4 fails to release.

To preserve all available power for the flight, two 5-wire cables are used for the leads to all parts of the instrument. These cables are of sufficient length to protrude a few inches through the gondola cover, each having a plug at the end, properly marked for identification (see Fig. 4). Two similar cables, also with plugs, come outside the gondola from the power supply. A few hours prior to the take-off, when the gondola has been put in place, the instrument, adjusted, is left operating on auxiliary batteries, which have two cables and plugs similar to those of the power-supply of the instrument. When ready for the take-off, the instrument is switched from the auxiliary to its own power, the operation taking less than one minute.

The antenna bus wire comes down from the antenna coil alongside the instrument and is brought out through the gondola base by means of the insulator P . The 120 ft. antenna has a small iron hook at the end to prevent too much swaying.

To protect the instrument from stratosphere temperatures

the gondola (Fig. 7) was built, in the manner developed by Prof. E. Regener. The upper portion of the Dow metal frame is covered with metallation (aluminum foil on heavy paper), while the lower part of the covering is celluloid. The bottom of the gondola is covered with heavy black paper. A black paper cylinder is attached to the lower part of the instrument, there being a space between the bottom of the cylinder and the gondola floor. The sun's radiation captured in the space between the celluloid cover and the black paper cylinder, will tend to set up circulation inside the gondola. A test, made on a freezing day, showed that the hot house effect amounted to a temperature difference of 45° F.

The total weight of the instrument, power-supply and gondola was 42 pounds 9.5 ounces.

Auxiliary Meter.

Since the instrument does not lend itself readily to a measurement of its constants, an auxiliary meter was built. This consists of the ionization chamber to be used in the flight, a connecting shield can with electromagnetic grounding key and a second electrometer, similar in construction and sensitivity to the one in the cosmic ray meter. Determination of voltage sensitivity, capacity, leakage, ionization chamber's own radiation and the total radiation, are measured using this auxiliary meter.

A few hours before the take-off, the ionization chamber, with the radium capsule in place, is moved from the auxiliary meter to the instrument. The total ionization current being known, the only observation to be made on the instrument is the time between two consecutive groundings of the electrometer. This time can be adjusted by changing the sensitivity of the Dershem electrometer, the position of the slot in shield can *G*, the bias on the discharge key and the sensitivity of the photocell amplifying circuit.

Since the instrument's signal time, as adjusted, corresponds to a known ionization current, the current corresponding to any other interval between two signals can be readily computed.

Balloons.

The balloons, three in number, were furnished by the Sterling Rubber Company of Guelph, Ontario, Canada, and were guaranteed to expand to at least 15 ft. diameter before exploding. They were made of only slightly vulcanized rubber, weighed between 7 and 8 lbs. each, and at the bottom had a 1" nozzle for inflation. On their equator they had eight heavy rubber loops, to be tied to the cords. By suspending the instrument and gondola by eight cords and arranging the balloons "in tandem" (one above the other), leaving ample space for expansion, tying each cord to one loop of each balloon, the strain on the balloons themselves is reduced to a minimum, the pull at each loop not being more than about 2 lbs.

By letting three and one-half foot balloons of known lifting power ascend at a greater speed than was to be used in the flight an empirical expression was found, for the relation between air drag (or net lifting power), diameter of the balloon and rate of ascent, of the following form:

$$R = 0.000145 V^2 D^2.$$

Here R is the air drag or required net lifting power in lbs., V is the velocity in ft./sec., and D is the diameter in feet. By net lifting power is understood the load which would have to be added to make the balloon float. This expression should be applicable for spherical balloons between 3.5 and 8 ft. diameter, when the product of the diameter in feet and the velocity in ft./sec. lies between 75 and 125. The coefficient 0.000145 contains amongst other things the density of the air through which the balloon moves. Assuming that the expression is valid for larger balloons moving through air of less pressure, as in ascending, then if the lifting power remains constant the rate of ascent should increase, because the density varies inversely with the cube of the diameter of the balloon, while D in the expression is only squared. In fact, V^2 should be proportional to the diameter of the ascending balloon.

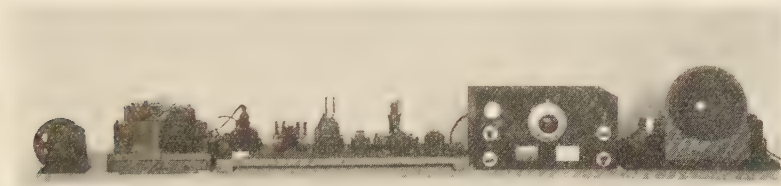
It is further suspected that the form factor contained in the coefficient decreases for larger balloons. This increase

in rate of ascent has been observed by Regener ⁶ in his flights in 1934, when the speed was more than doubled at 70,000 ft. A similar increase was noted during the present balloon flight.

Receiving Apparatus.

Figure 5 shows the apparatus used for the reception of the signals. A 47 vacuum tube is coupled inductively to the

FIG. 5.



Receiving apparatus.

From left to right: tape winder, Western Union Telegraph Co. "Undulator," full wave rectifier and No. 47 vacuum tube, National Company H. R. O. short wave receiver, loud speaker and power pack.

output circuit of the short wave receiver and the changes in its plate current are inductively transferred to the recording device, which is a Western Union Telegraph Company undulator. As it was feared that atmospherics or other interference might blur the written record, the receiver was also equipped with a loud speaker, which proved to be of the greatest value during the experiment.

PREPARATION FOR THE FLIGHT.

Permission was obtained from Mr. H. L. Mitchell, Commissioner of the Department of Streets and Parks of Shreveport, La., to make the flight from the city's Municipal Airport. In the beginning of the month of April, 1936, a 28 ft. X 40 ft. observation tent was erected at the airport to house the receiving apparatus and the other equipment.

On April 11th the instrument radiation was determined with the auxiliary meter, in the salt mine of the Carey Salt Company, near Winnfield, La. The local plus cosmic radiation was measured in the observation tent on the nights of

⁶ Regener, International Conference on Physics, 1934. I. Nuclear Physics, 254.

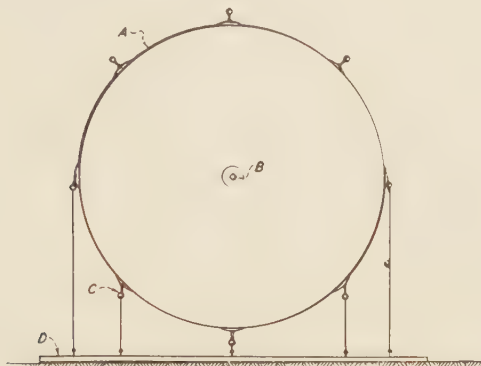
April 12th and April 13th. Inspection of the weather map of April 13th showed absence of pronounced pressure maxima or minima over the southern part of the United States, Shreveport being in a minimum area. Barometric pressure during the week ending April 13th averaged 29.90 inches with maximum fluctuations of 0.2 inch from the average.

On April 13th Lieutenant R. M. Losey, stationed at March Field, Riverside, Calif., who had kindly offered his assistance, advised that for the week beginning April 14th, the best flight conditions would prevail on the morning of April 14th after sunrise. It was decided to attempt the flight at that time.

At 00:30 A.M. of April 14th, after the second set of readings for the local plus cosmic radiation had been made, the capsule with radioactive material was attached to the ionization sphere and the added ionization determined, all on the auxiliary meter. At 1:00 A.M. the ionization chamber, with the capsule in place, was moved from the auxiliary meter to the instrument, and the time between successive electrometer discharges adjusted to an average of 225 seconds. Inflation of the balloons began at 2:30 A.M. They were laid on woolen blankets and inflated with hydrogen, until they almost lifted their own weight. The equatorial loops were then attached by means of hooks and strings to a piece of $2'' \times 4'' \times 10'$ lumber, which served as anchor (see Fig. 6). Since the excess pressure inside the balloons is negligible (not more than 3 cm. of water), the nozzles were closed by inserting small round metal cups, which facilitated the filling and weighing. By placing the wood anchor and balloon on scales the net lifting power can be determined within an ounce without difficulty. The balloons' diameter, after inflation, was about 8 feet, the time for inflating and weighing each balloon being thirty minutes. At 5:00 A.M. the gondola was put over the instrument, which was then left suspended and operating on the auxiliary batteries, and the antenna was attached. Shortly after sunrise the inflated balloons, still attached to their anchors, were brought outside the observation tent and placed thirty feet apart, two men handling one balloon. The cords were tied to the equatorial loops on the balloons and to the instrument and gondola, which had been brought from

the observation tent at the proper time after the change from auxiliary to own power had been made.

FIG. 6.



Showing manner in which balloons were handled after inflation.

When ready, the balloons were allowed to rise slowly, one after the other, and finally the instrument released.

THE FLIGHT.

The take-off was at 7:08 A.M. (Fig. 7). The weather conditions were very favorable. The balloons were aloft until 9:36:55 A.M., when they landed three miles north of Arcadia, La., forty-eight miles east of Shreveport. An airplane followed the balloons, flying at 13,000 feet. The position of the balloons was measured by engineers every five minutes from a base line, east of the airport, until 8:25 P.M. The pilot landed at Arcadia, La., emptied two of the balloons, the lower one having exploded at 9:10 A.M., five miles south of Arcadia, La. The apparatus and balloons were moved back to Shreveport the same day. During the entire flight the radio reception was good. The tape record was fair for the beginning and end of the flight, interference blurring the record during the middle part of the flight. The audible record, however, was very good and the signals could be heard plainly at considerable distance from the receiving apparatus. Four observers were used to record the signals and keep the receiving apparatus adjusted.

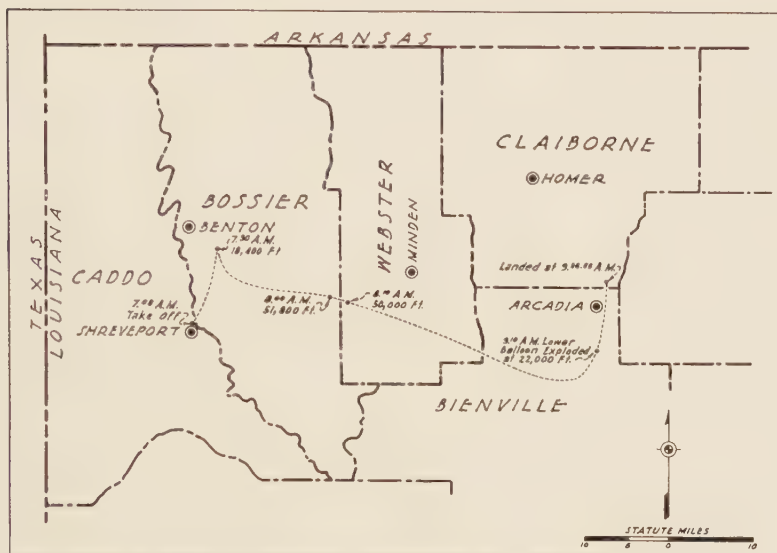
FIG. 7.



The take-off.

From the engineers' data and the position report of the pilot, the path of the balloons can be fairly accurately determined. It is shown in Fig. 8. At 7:30 the balloons were

FIG. 8.



Index map of N.W. Louisiana showing approximate path and altitude of the balloons. The wind up to 20,000 feet was S.S.W., above 20,000 feet it was W.N.W.

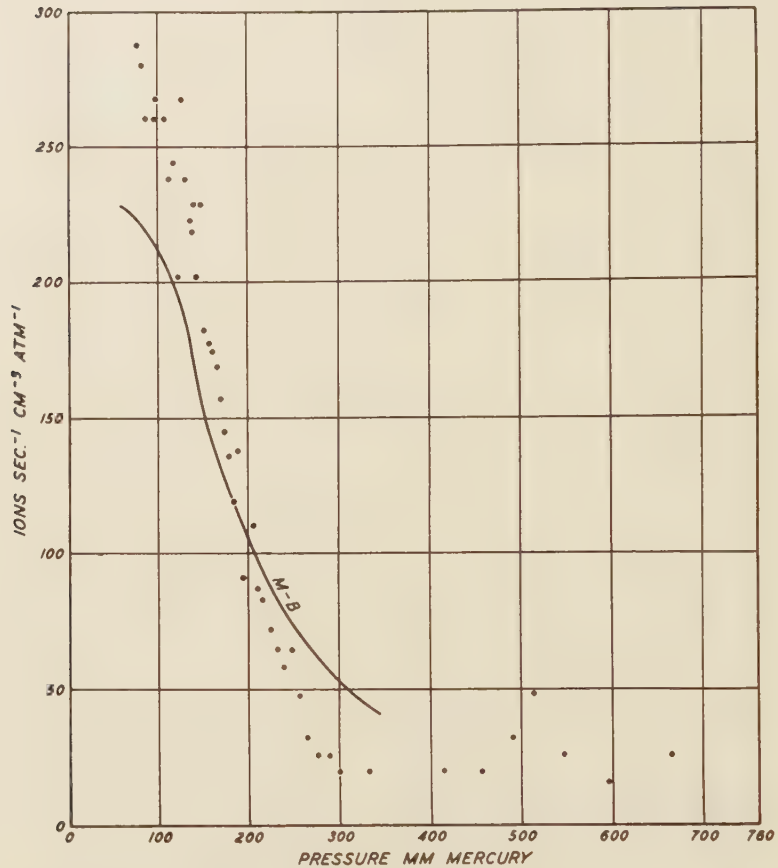
near Benton, La., at an altitude of 18,400 feet. At 8 A.M. they had reached 52,000 feet and were near Minden, La. They then descended rather slowly to 22,000 feet during the following seventy minutes, when they had reached a position south of Arcadia, La., and the lower balloon exploded.

RESULTS.

The 48 cosmic ray signals received during the ascent have not been computed, because the time intervals, although decreasing from 225 seconds at the take-off to 55 seconds at the top of the flight, are too irregular. This irregularity is attributed to the motion of the electrometer mirror, which, through its fine quartz fiber suspension, was too much influenced by the swaying of the gondola. The remaining 49 signals, 42 of which were received during the slow descent to

22,000 feet, have been computed and plotted against pressure in Fig. 9, the last seven corresponding in time to the rapid

FIG. 9.



Ionization plotted against pressure, computed from data received during the flight. The solid line, marked *M-B*, was obtained by Millikan and Bowen in 1932 at Dallas, Texas, 200 miles W. of Shreveport, La.

descent to earth after the explosion of the lower balloon at 9:10 A.M.

The pressure device functioned fairly satisfactorily. Based on the experience of this flight, the belief is stated that a device which gives the existing pressure continuously is preferable over one which only signals the pressure at intervals.

These data are submitted to show what results can be expected from the method, rather than as a measurement, establishing the values of cosmic ray intensities in the high altitudes at Shreveport, La. For comparison the curve obtained by Millikan and Bowen⁷ in their Dallas, Texas, flights in 1932, has also been plotted in Fig. 10 (solid line marked *M-B*).

ACKNOWLEDGMENTS.

In conclusion I wish to thank Prof. A. H. Compton and Dr. R. L. Doan for many helpful conversations at the Ryerson Laboratory, University of Chicago, and Mr. M. R. Hebert, of the Air Navigation Division, Department of Commerce, stationed at Shreveport, La., whose knowledge of radio instrumentation and radio communication was of great help in building the apparatus and carrying out the experiment.

⁷ Bowen and Millikan, *Phys. Rev.*, **43**, 695, 1933.

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